Future HEA Missions and Upcoming Decadal Survey
HEAD 2008

The Generation-X Astrophysics Strategic Mission Concept Study

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Gen-X Astrophysics Strategic Mission Concept Study (AMCS) Proposal

- Gen-X: large area, high angular resolution X-ray telescope to study the early universe, evolution of BH, galaxies and elements, and extreme physics
- Follows Chandra, XMM-Newton and Con-X
- Study will build on the successful 2004-05 Vision Mission study
- Revisit science case to refine mission requirements
- Ares V capability results in simplified and more cost-effective baseline mission concept
- Key Study product is a detailed technology development road map
Generation-X AMCS Team

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- Steve Kahn
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and collaborators

67 People, 21 Institutions
5 Industry Partners
2 NASA Centers
Generation-X Science Drivers

- **EARLY UNIVERSE:** The first black holes, stars and galaxies
  - X-rays penetrate haze of high z IGM, and gas and dust around objects
  - Provide a channel to z>6 and the EOR

- **EVOLUTION:** of black holes, galaxies and the elements they produce vs cosmic time
  - X-ray observations trace baryon abundances and dark matter since much baryonic matter in form of hot gas (elliptical halos, clusters)

- **PHYSICS:** Probe the behaviour of matter in extreme environments
  - Density, gravity, magnetic field, kinetic energy

- **Science drivers traced to observations to mission parameters and implementation**
### Gen-X Mission Parameters Derived from Science Objectives

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective Area (@1 keV)</td>
<td>50 m²</td>
</tr>
<tr>
<td>Angular Resolution</td>
<td>0.1&quot; HPD</td>
</tr>
<tr>
<td>Energy Resolution (@1 keV)</td>
<td>E/dE=3000</td>
</tr>
<tr>
<td>Background (0.5 – 2.0 keV)</td>
<td>0.004 cts/ks/arcsec²</td>
</tr>
<tr>
<td>Energy Range</td>
<td>0.1 – 10 keV</td>
</tr>
<tr>
<td>Field of View</td>
<td>5 arcmin radius</td>
</tr>
<tr>
<td>Time Resolution</td>
<td>50 µs</td>
</tr>
<tr>
<td>Count Rate Limit</td>
<td>100 cts/sec/pix</td>
</tr>
<tr>
<td>Sky Availability</td>
<td>90%</td>
</tr>
<tr>
<td>Calibration</td>
<td>3% absolute</td>
</tr>
<tr>
<td>Launch Vehicle and Orbit</td>
<td>Ares V to Sun-Earth L2</td>
</tr>
<tr>
<td>Launch Date</td>
<td>2025-2035</td>
</tr>
</tbody>
</table>
Detecting the First Black Holes

- First epoch of energy injection at z~10-20 (0.2-0.5 Gyr) - WMAP
- Fast burning massive stars yield SN and first black holes
- Must grow at Eddington limit to reach observed quasar masses
- Fiducial numbers for Gen-X:
  
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black Hole Mass</td>
<td>1000 solar masses</td>
</tr>
<tr>
<td>Eddington Limit</td>
<td>$6.5 \times 10^{40}$ erg/s</td>
</tr>
<tr>
<td>Redshift</td>
<td>15</td>
</tr>
<tr>
<td>Flux</td>
<td>$3 \times 10^{-20}$ erg/cm$^2$/s</td>
</tr>
<tr>
<td>Effective Area</td>
<td>50 m$^2$</td>
</tr>
<tr>
<td>Angular Resolution</td>
<td>0.1&quot;</td>
</tr>
<tr>
<td>Count rate</td>
<td>$5 \times 10^{-6}$ cts/sec</td>
</tr>
<tr>
<td>Exposure time</td>
<td>$1 \times 10^6$ s (~5 counts in 1 Ms)</td>
</tr>
<tr>
<td>Background rate</td>
<td>0.01 cts/ks/arcsec$^2$</td>
</tr>
</tbody>
</table>

- Drives 50 m$^2$ Effective Area and 0.1" Angular Resolution
Merging Black Holes and AGNs

- Merging black holes give insight into merger tree vs. redshift
- X-rays can see accreting black holes even for $A_V=100$
- Gen-X: 160 ks, $z=1$, can detect and resolve a binary AGN 2kpc apart.

- 0.1" resolution corresponds to physical scales of:
  - 0.8 kpc at $z=3$
  - 0.6 kpc at $z=6$
  - 0.3 kpc at $z=15$

- Hundreds of binary BH systems observable with separation of ~1 kpc

- Drives $EA=50 \, m^2$, Ang. Res=0.1", $E/\Delta E=10^3-10^4$
Gen-X View of Galaxy Evolution

- Gen-X sufficiently resolves the dominant X-ray binaries to allow X-ray ‘Population Synthesis’ and study of galaxy evolution
- Study chemical evolution with SNR to 10 Mpc; high resolution spectra of Fe, Si and O drives requirement $E/\Delta E = 10^3 - 10^4$

Simulated interacting galaxies to $z=1$
Vision Mission Study Results

- Preliminary Technology Development Roadmap
- Two mission concepts developed
- Formation Flying
  - 100 m² EA at 1 keV
  - 20m diameter mirror, 125m focal length
  - Multiple launches to LEO, assemble mirror and transfer to L2; Instrument craft direct to L2
- 6 identical telescopes
  - 16 m² EA at 1 keV
  - 8 m diameter, 50 m focal length
  - Detectors attached to deployable boom
  - 6 ELV launches (e.g., Delta 4H) to L2
- Detectors
  - Micro-calorimeter array
  - Active pixel imager
  - X-ray grating spectrometer
Gen-X Baseline AMCS Mission

- Ares V enables simplified & more cost-effective mission concept
- Single spacecraft
  - 16 m-diameter deployable optic, ~50 m² effective area
  - Piezo-electric control of optic figure on-orbit to achieve ~0.1" angular resolution
  - 60 m focal length with extendable optical bench
  - Mirror folds to fit within 10m fairing dynamic envelope
- Deliver Gen-X directly to Sun-Earth L2
- Spacecraft mass estimate of 22 Metric Ton (MT) well within Ares V 60 MT capability to L2
Reference Spacecraft Configuration

Ares V Stowed Configuration

- Telescope Sunshade
- Grazing Incidence X-ray Optics
- Extendible 60 m Optical Bench
- Grating Array
- Spacecraft Bus and Science Instruments
**Study Focus: Technology Development Plan**

- **Telescope and Optics**
  - Figure: on-orbit adjustment
  - Modules: alignment
  - Deployment

- **Science Instruments**
  - XMS: array pixel count, energy resolution
  - WFI: read noise, pixel size, dark current
  - XGS: ruled grating

- **Spacecraft and Mission**
  - Solar collector and thermal control system
  - Deployables: optical bench, sun shade
  - VM Study found s/c at TRL 4-6

➤ **Optics are the major driver**
Active Optics Mirror: Bimorph Piezoelectric Actuators

- No need for reaction structure
- Low power, weight
- Natural match to thin reflectors (0.2 mm)
- Mechanical actuators: hysteresis, backlash, lubricants
- Similar technology under development at synchrotrons
- R&D efforts underway at SAO
## Preliminary Gen-X Technology Development Roadmap

<table>
<thead>
<tr>
<th>System</th>
<th>Technology</th>
<th>Heritage</th>
<th>Present Capability</th>
<th>Requirement</th>
<th>TG1</th>
<th>TG2</th>
<th>TG3</th>
<th>TG4</th>
<th>TG5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mirror</td>
<td>Mirror Figure</td>
<td>XMM, Con-X</td>
<td>Adjust to: 10Å over 1m</td>
<td>40Å over 0.1 m</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Mirror</td>
<td>Mirror Modules</td>
<td>XMM, Con-X</td>
<td>~100 shells aligned to ~3”</td>
<td>~200 shells aligned to 0.05”</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>Mirror</td>
<td>Deployment</td>
<td>JWST</td>
<td>Mechanism heritage</td>
<td>Alignment of modules to 0.05”</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>XMS</td>
<td>Multiplexing Pixel Array</td>
<td>Suzaku, Con-X</td>
<td>6x6 (Suzaku)</td>
<td>1800 x 1800</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>Energy</td>
<td>Resolution</td>
<td>Suzaku, Con-X</td>
<td>6eV at 5.9keV (Suzaku)</td>
<td>2 eV@6 keV</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>Grating</td>
<td>Transmission Reflection</td>
<td>Einstein</td>
<td>~5000 lp mm⁻¹</td>
<td>~10³ lp mm⁻¹</td>
<td>2-3</td>
<td>4-5</td>
<td>6</td>
<td></td>
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<tr>
<td>Grating</td>
<td>Active Pixel Imager</td>
<td>XMM, Chandra</td>
<td>Einstein</td>
<td></td>
<td>2-3</td>
<td>4-5</td>
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<tr>
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<td></td>
<td>JWST</td>
<td>Einstein</td>
<td></td>
<td>2-3</td>
<td>4-5</td>
<td>6</td>
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<td></td>
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<tr>
<td>Grating</td>
<td></td>
<td></td>
<td>Read noise: 10e⁻ @50Hz</td>
<td>2e⁻ @ 1 MHz</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>WFI</td>
<td>Transmission Reflection</td>
<td>Einstein</td>
<td>~5000 lp mm⁻¹</td>
<td>~10³ lp mm⁻¹</td>
<td>2-3</td>
<td>4-5</td>
<td>6</td>
<td></td>
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<tr>
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<td>JWST</td>
<td>Einstein</td>
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<td>2-3</td>
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<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>WFI</td>
<td></td>
<td></td>
<td>Read noise: 10e⁻ @50Hz</td>
<td>2e⁻ @ 1 MHz</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>WFI</td>
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<td>Size: 128x128</td>
<td>4000x4000</td>
<td>2-3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<td>WFI</td>
<td></td>
<td></td>
<td>Depletion Depth: 15 µm</td>
<td>100 µm</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
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<tr>
<td>WFI</td>
<td></td>
<td></td>
<td>Vid. Processor: 36 parallel channels</td>
<td>1000 parallel channels</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>
Conclusions

- Gen-X key science goals: observe the first black holes, stars and galaxies, and trace their evolution
- Large area: 50 m², high resolution: 0.1" requires innovative active approach to mirror figure control
- Study baseline:
  - 16 m-diameter deployable optic
  - 50 m² effective area
  - 60 m focal length
  - SI’s on extendable boom
  - Ares V Launch to L2
- Ares V enables Gen-X: streamlined and cost effective mission design and launch
- Study will produce Technology development plan with emphasis on optics for presentation to the Decadal Survey.